Health at the onset of old age

Arda Aktas[1] Warren C. Sanderson[1,2,3] Sergei Scherbov[1,2]

[1] International Institute for Applied Systems Analysis, Schlossplatz 1, A-2361 Laxenburg, Austria.

[2]Wittgenstein Centre for Demography and Global Human Capital (IIASA, VID/ÖAW, WU) Welthandelsplatz 2, Level 2, 1020 Vienna, Austria.

[3]Department of Economics, Stony Brook University, N-631 Social and Behavioral Sciences Building, Stony Brook, NY, USA.

* The authors contributed equally, and their names are listed in alphabetical order. This study was supported by the European Commission Horizon 2020 under grant number 635316 (ATHLOS).

This is a preliminary draft. Please do not cite or distribute without permission of the authors.

Abstract

In population studies, there is a need for new aging measures which reflects the improvements in health and longevity. We bring two important ageing-related characteristics, life expectancy and health, together under the framework of "Characteristic Approach" to create a dynamic age measure which we call ''Prospective Health Age'' (PHA). Using a novel composite metric of health developed as part of the ATHLOS project, we compare the level of health of different birth cohorts in England and the US at the onset of old age which is defined based on fixed chronological age (i.e., conventional approach) such as age of 65 and fixed years of remaining life expectancy (i.e., prospective approach). We show that people, at the prospective old age threshold, have roughly the same level of the composite health metric regardless of when they were born or whether they are English or American. Hence, we use the constant values of the composite health metrics for women and men to define "prospective health-age thresholds'' which are the ages at which the average level of health in population subgroup equals those constant values. An analysis of prospective health-age thresholds shows that there are significant disparities in health across educational categories, genders and countries. In particular, we show that health inequality across education groups was greater in the US than in England.

Keywords: Aging, health, aging trajectories, prospective old age thresholds, education

Introduction

Over the last century, improvements in living conditions and medical progress have led to significant increases in the life expectancy of people. Despite these changes, the concepts and methods used to measure population ageing have not changed much. Indeed, the term "elderly" still refers to persons who have lived up to or beyond some certain ages. However, this approach may be misleading as people with different characteristics experience the process of ageing differently. For example, people of different generations may age at different rates. People who are 65 years old today are, on average, in much better physical and mental condition [1, 2], and generally expect to enjoy longer lives [3-5] than people of the same age in the past. Consequently, the average 65 years old individual of today may not be really as "old" as their earlier counterparts.

In order to keep up with this evolving reality, Sanderson and Scherbov developed the "Characteristics Approach" [6-8] and proposed the creation of new measures of ageing based on people's ageing-related characteristics, such as remaining life expectancy. Using this framework, they re-defined the boundary of old age based upon a fixed number of years of remaining life expectancy and called this new measure the "prospective old age threshold (POAT)" [7, 9]. Based on this new definition of old, they showed that many regions that were considered to be suffering of the "aging population problem" show almost no sign of aging in the past years.

Another important characteristic related to the ageing process is health. In fact, mortality rates are widely used as an imperfect measure of population health for cross-country comparisons (e.g. [10]). However, health is also a multidimensional phenomenon and it involves several factors beyond mortality. Measuring health has been challenging, especially at the individual level. Some of the measures used to reflect individual health are dependent on subjective self-reported evaluations (e.g. self-rated health), measures of ability to function independently (e.g. ADLs and IADLs), or morbidity indicators (e.g. whether an individual is or has suffered a particular disease) [1]. However, none of these measures can be considered both comprehensive and objective representations of overall health. To address these shortcomings, a novel composite metric of health was developed in Caballero et al. [12] as part of the Ageing Trajectories of Health: Longitudinal Opportunities and Synergies (ATHLOS) Project. This new measure can be used to create health-age trajectories and, therefore, analyze health status of different populations at different time.

Our study combines these two important ageing-related characteristics, life expectancy and health, under the framework of "Characteristic Approach" to create a new age measure which we call ''Prospective Health Age'' (PHA). In simple terms, we find the average health of different populations at the time the average remaining life expectancy is 15 years, and, posteriorly, calculate the specific ages at which subpopulations reach this level of health. This new measure allows us to analyse the trajectories of health at the onset of old age for different populations.

This paper proceeds in two steps. First, we compare the health-age trajectories of different birth cohorts observed in the English Longitudinal Study of Ageing (ELSA) and in the US Health and

[1] See [11] for a discussion of different measures of health used for cross-country comparisons.

Retirement Study (HRS) using chronological and prospective based definitions of "old age''. One desirable feature of an old age threshold is that people just entering the stage of old age should have roughly the same health regardless of when they were born. We find that the health of individuals at the same chronological age, but of later birth cohorts is always higher than the health of individuals in earlier birth cohorts. On the contrary, people with the same prospective age in subsequent cohorts have roughly the same level of health.

Posteriorly, we use this feature of the POAT to define the level of health at the onset of old age, and based on this, we develop the "prospective health age (PHA)". Using this new measure, we compare the aging trajectories by levels of education in the US and England. We find that there are significant disparities in health across educational categories, gender and countries that lead to a faster aging process for some population subgroups than others do. In particular, between different education categories, the inequality in health is so large that it creates approximately 10 years difference in PHAs. Across countries, we find that the average difference in PHAs by education is always lower in ELSA than in HRS for both genders, implying a larger health gap in the US than in England. We also observe that the improvements in health in the US fall behind those in England, affecting particularly high school dropouts negatively. The key findings we outline above are consistent across genders but always larger for males than females.

The contribution of this paper to threefold. First, using a novel measure of health, we show that the POAT reflects the health-aging nexus better than the conventional fixed chronological old age threshold does. Second, it provides a framework to define ``old age'' based on life expectancy and health. The proposed measure can be used in a variety of contexts and facilitate comparisons of health-age trajectories across different populations. Third, using our new measure, we show that there is an increasing inequality in health by education, implying a much faster aging for those with low levels of education. It also has an important policy implication as it gives additional support to the argument that increasing the education level of the population could imply significant gains in terms of healthy ageing.

The rest of the paper is divided into four sections. The first briefly describes the data and the health measure used in the analysis. The second summarizes the methodology applied to determine health-age trajectories and compare the trajectories in aging considering the definition of ``elderly'' in terms of chronological age and remaining life expectancy. The third introduces the new old age threshold based on health and remaining life expectancy and use it to compare the aging patterns of people with different education levels. The final section discusses the results and concludes.

1. Data

Our analysis is based on two longitudinal surveys of non-institutionalized individuals over the age of 50, the US Health and Retirement Study (HRS) and the English Longitudinal Study of Ageing (ELSA). We focused on an ELSA subsample of 12,686 white individuals (6,685 females and 6,001 males) and a subsample of 25,542 white individuals from HRS (13,910 females and 11,632 males) with ages ranging from 50 to 80 in the years 2002 to 2012.

Health is measured using an individual-based composite health metric developed in Caballero et al. [12] as a part of ATHLOS project. For the estimation of this health metric, a Bayesian Multilevel Item Response Theory methodology was used on a set of health-related items including self-reported health questions and measured tests obtained from longitudinal household surveys. The index was further expanded in de la Fuente et al. [13] for a joint panel of 6 waves of the English Longitudinal Study of Ageing (ELSA), taken every other year between 2002 and 2012, and 11 waves of the Health and Retirement Study (HRS) from the years 1992 to 2012. The version of the health metric used in our analysis is the latter one. It was estimated based on 45 health characteristics observed in seven waves of ELSA and 30 of these characteristics observed in 11 waves of HRS[2]. The health score take values on a 0 to 100 scale, with higher values indicating better health.

2. Comparison of health trajectories based on different definitions of old age

Health and ageing are closely related, as people's health naturally declines as they age. Therefore, a logical test of the appropriateness of an old age threshold is that it changes so as to keep the average level of health constant across time. Based on this criterion, we compare the health-age trajectories of different birth cohorts observed in ELSA and HRS. Particularly, we focus on the health levels of different cohorts at the onset of old age.

The onset of old age is defined in two ways. The conventional old age threshold assumes that people are categorized as old at a fixed chronological age, usually at age 65. The alternative, the prospective old age threshold (POAT) proposed by Sanderson and Scherbov [6 -9], defines the onset of old age as depending on remaining life expectancy. Here, we set the POAT at the age where the remaining life expectancy is 15 years. Formally, let $e_{i,t}(.)$ be the life expectancy of the population group i at time t. The calculation of the POAT is therefore carried out using the following equation:

$$POAT_{i,t} = e_{i,t}^{-1}(15),$$

where $POAT_{i,t}$ is the prospective old age for gender i in year t and $e_{i,t}^{-1}(15)$ is the age in the life table of gender i in year t where the remaining life expectancy is equal to 15 years (see Appendix A for a hypothetical calculation of POATs based on life expectancy).

The analysis followed a two-step process. First, a calculation of the POAT was carried out independently for each subgroup. In order to do that, using a Cox-Gompertz model, we calculate survival curves and construct life tables for each sample and gender independently and then, based on these estimated life expectancies, we calculate the POATs. The results are shown in Table 1. As expected, males have lower life expectancy and, therefore, a lower POAT than females. The gap, on average, is 2 years in ELSA, and around 3.5 years in HRS. More importantly, there is a substantial cohort effect. Indeed, between 2002 and 2012, life expectancy increased by 3 years for females and about 4.6 years in the case of males in ELSA. The corresponding figures in the HRS sample are relatively smaller than those in ELSA (1.5 and 1.8 years for females and males), but still not negligible. This, by itself, provides a strong counterargument against fixing the beginning of the old age at a static chronological age.

[2] Details of the methodology and the health characteristics used can be seen in Caballero et al. [12] and de la Fuente et al. [13].

Table 1: Prospective old age thresholds (POAT) by gender for England and USA, 2002 to 2012

	Prospective Old Age Thresholds (in years)			
	England		USA	
Year	Female	Male	Female	Male
2002	70.75	67.99	71.93	68.42
2004	71.36	68.93	72.24	68.79
2006	71.97	69.87	72.55	69.16
2008	72.57	70.80	72.86	69.53
2010	73.17	71.71	73.16	69.90
2012	73.75	72.60	73.47	70.26

Source: Authors' calculations.
Note: POATs are the chronological ages at which remaining life expectancy is 15 years.

In the second step, we estimate the representative paths of health at older ages for individuals of subsequent cohorts. The health measure used in the analysis implies a wide distribution of health scores for individuals in both samples according to the responses related to the health-related items. Therefore, in order to trace the representative health of individuals of different birth cohorts at different ages, we use a least squares methodology. Specifically, we fit second-degree polynomial curves of the health score on age and year form independently by gender. As the measure devised by de la Fuente et al. [13] provides multiple, but not specifically path-dependent[3] observations of individual health, we take 100 random draws of both ELSA and HRS panels containing a single observation per individual and, for each random subsample, estimate the following model:

$$health_i = \alpha_0 + \alpha_1 * age_i - \alpha_2 * age^2{}_i + \alpha_3 * wave_i + \varepsilon_i \quad (1)$$

Table 2: Coefficients of the fitted second-degree polynomial health curves

Coefficient	$ELSA_{female}$	$ELSA_{male}$	HRS_{female}	HRS_{male}
$constant$	42.182***	74.785***	68.479***	58.120***
	(5.069)	(5.832)	(4.653)	(5.347)
age	0.980***	-0.014	0.004	0.368*
	(0.160)	(0.183)	(0.141)	(0.168)
age^2	-0.011***	-0.003*	-0.003**	-0.006***
	(0.001)	(0.001)	(0.001)	(0.001)
$wave$	0.458***	0.598***	0.123*	0.291***
	(0.056)	(0.058)	(0.061)	(0.063)

Notes: Coefficients are the averages of 100 OLS estimates of health on age, age^2 and survey year by gender. Standard errors are in parentheses. ***p < 0.001; **p < 0.01, *p < 0.05, 'p < 0.1

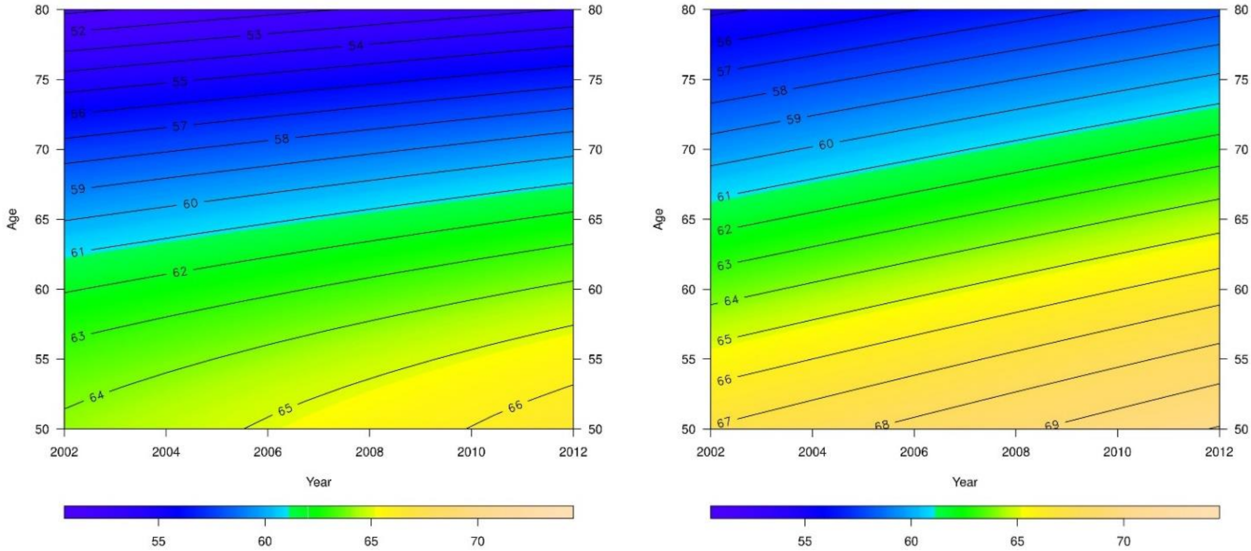
In Table 2 we present the average estimated coefficients, as well as the standard deviations. All coefficients estimates are found to be statistically different than zero and significant at various levels, same for the linear age coefficients for the ELSA male and HRS female subsamples. However,

[3] In particular, an individual that possess the same set of health characteristics at subsequent points in time is not assumed to have the same health score (i.e., $health_{it+1} \neq health_{it}$) nor any form of individual-specific autocorrelation (i.e $health_{it+1} \neq \rho health_{it} + \varepsilon_t$), but a health score that comes from the same underlying distribution (i.e., $health_{it+1} \sim F(\theta) \wedge health_{it} \sim F(\theta)$).

for all cases, we observe a significant effect of age and wave supporting the argument that health decreases with age and increases over cohorts.

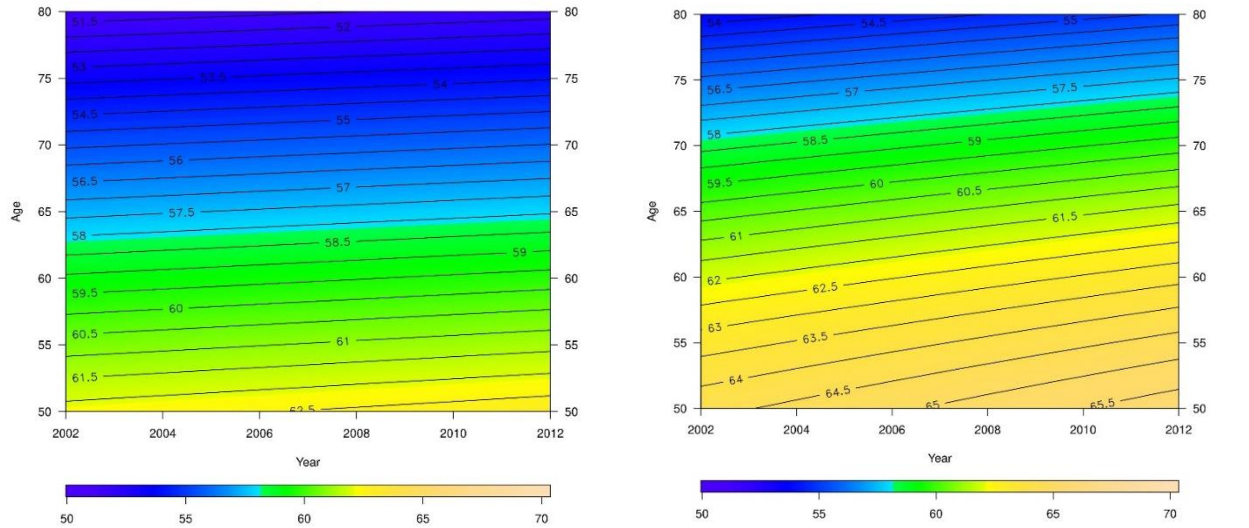
Using the estimated coefficients, we calculate levels of health for the different samples, genders, ages and years. The estimated health-age-year trajectories can be seen in Figures 1 and 2. As shown in both figures, on average, the health of individuals at the same chronological age, but of later birth cohorts is always higher than the health of individuals in earlier birth cohorts.

Figure 1: Trajectories of health by gender at different ages and years, England (ELSA)



(a) Females (b) Males

Figure 2: Trajectories of health by gender at different ages and years, USA (HRS)



(a) Females (b) Males

NOTE : Health trajectories are calculated using the regression coefficients presented in Table 2.

Tables 3 and 4 provide information on the average level of health of different birth cohorts at the onset of old age. We can see that, at age 65 (i.e., the standard static fixed old age threshold), the health score of successive cohorts is always increasing, while at the POAT[4] (i.e., dynamic old age threshold based on remaining life expectancy) the health levels remain almost constant. For example, the health score of the average 65 years old female in England increased from 59.95 in 2002 to 62.24 in 2012. The corresponding numbers for men in England are 61.61 in 2002 and 64.6 in 2012, indicating an almost 5 percent increase in the health score within ten years. Similarly, the health score of the average 65 years old male in the USA increases approximately 1.6 percent in the same period.

Table 3: The level of health at fixed old age threshold (i.e., age 65) and at prospective old age threshold (POAT)* in England, males and females, 2002 to 2012

		ELSA			
		Health at age 65		Health at POAT	
Gender	Year	Mean	CI (95%)	Mean	CI (95%)
Female	2002	59.95	[59.59, 60.32]	57.02	[56.74, 57.30]
	2004	60.41	[60.12, 60.70]	57.12	[56.92, 57.32]
	2006	60.87	[60.62, 61.12]	57.22	[57.03, 57.41]
	2008	61.33	[61.08, 61.58]	57.31	[57.07, 57.56]
	2010	61.79	[61.49, 62.08]	57.40	[57.06, 57.74]
	2012	62.24	[61.87, 62.61]	57.49	[57.04, 57.93]
Male	2002	61.61	[61.23, 61.99]	60.36	[60.02, 60.70]
	2004	62.21	[61.91, 62.51]	60.55	[60.30, 60.08]
	2006	62.81	[62.56, 63.06]	60.74	[60.53, 60.94]
	2008	63.40	[63.16, 63.65]	60.93	[60.69, 61.16]
	2010	64.00	[63.72, 64.29]	61.12	[60.80, 61.44]
	2012	64.60	[64.24, 64.96]	61.31	[60.88, 61.74]

Source: Authors' calculations using the regression coefficients in table 2.
Note: *POATs are the chronological ages at which remaining life expectancy is 15 years.

Table 4: The level of health at fixed old age threshold (i.e., age 65) and at prospective old age threshold (POAT)* in USA, males and females, 2002 to 2012

		HRS			
		Health at age 65		Health at POAT	
Gender	Year	Mean	CI (95%)	Mean	CI (95%)
Female	2002	57.32	[56.96, 57.69]	54.62	[54.36, 54.89]
	2004	57.45	[57.16, 57.73]	54.62	[54.43, 54.81]
	2006	57.57	[57.33, 57.80]	54.61	[54.43, 54.80]
	2008	57.69	[57.45, 57.94]	54.61	[54.36, 54.86]
	2010	57.82	[57.51, 58.12]	54.61	[54.26, 54.95]
	2012	57.94	[57.55, 58.33]	54.60	[54.14, 55.06]
Male	2002	60.24	[59.83, 60.65]	58.96	[58.59, 59.32]
	2004	60.53	[60.21, 60.86]	59.10	[58.83, 59.38]
	2006	60.82	[60.56, 61.09]	59.24	[59.01, 59.48]
	2008	61.11	[60.86, 61.37]	59.39	[59.13, 59.65]
	2010	61.40	[61.10, 61.71]	59.52	[59.19, 59.86]

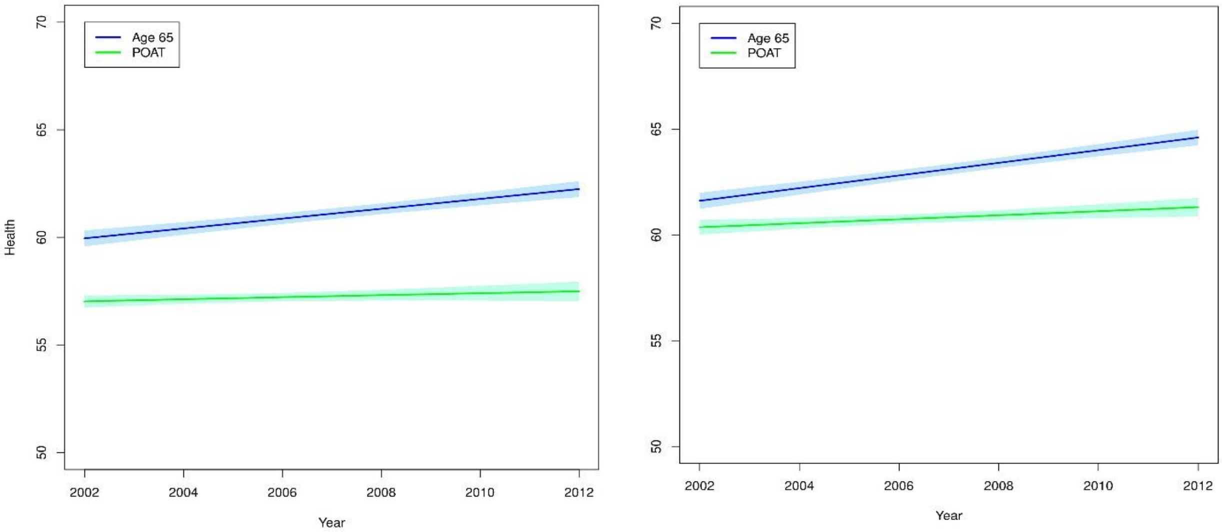
[4] Note that the ages used in the calculation of the POAT change every year as shown in Table 1.

	2012	61.69	[61.31, 62.08]	59.67	[59.22, 60.11]

Source: Authors' calculations using the estimated coefficients in table 2.
Note: *POATs are the chronological ages at which remaining life expectancy is 15 years.

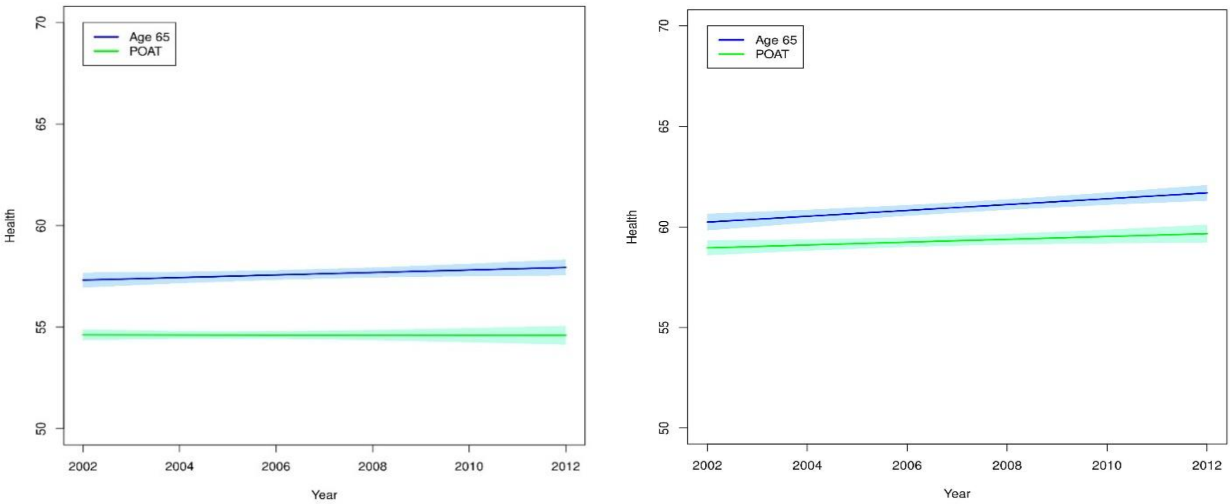
This can be further seen in Figures 3 and 4, which include the confidence interval of these calculations. Effectively, at a fixed old age threshold we see an upward trend, while at the POAT the trend is statistically flat. This implies that, in terms of health, the average 65 years old individual of the year 2012 is not as "old" as the average 65 years old individual of the year 2002. On the contrary, the health levels at the POAT of individuals belonging to different birth cohorts remains almost the same, pointing to similar levels of ageing. Given these results, if we consider that ageing is always accompanied by a decrease in health, a fixed chronological age does not provide an appropriate base for intergenerational comparisons of the ageing process.

Figure 3: Comparison of trajectories of health: At age 65 with those at prospective old age thresholds (POAT), England (ELSA), 2002 to 2012



(a) Females (b) Males

Figure 4: Comparison of trajectories of health: At age 65 with those at prospective old age thresholds (POAT), USA (HRS), 2002 to 2012



(a) Females (b) Males

3. Prospective health ages

As stated before, the "Characteristics Approach" of Sanderson and Scherbov provides a framework to create new age measures according to some of characteristics that are relevant for ageing[5]. Using this approach, we can translate the difference in the levels of health across population subgroups into an index measured in years, allowing us to make a simple and straightforward comparison of the aging trajectories across various population subgroups based on health.

To calculate it, we start from the findings in the previous section that people of different birth cohorts have roughly the same level of health at the POAT. Thus, based on the average health level at POAT, we define the health at the onset of old age and call it "prospective health age threshold (PHAT)". In line with Characteristic Approach, the chronological ages that corresponds to this fixed level of health give us the "Prospective Health Ages (PHA)".

For example, let us assume that we want to calculate the PHA of females with college education in HRS in 2002. For this, we first take the average health level of females at POAT as a baseline; call it "Prospective Health Age Threshold (PHAT)". Using the results from the estimations on the 100 random subsamples of both ELSA and HRS, we find that the PHAT for females equals to 55.94. Now, we want to see the chronological age of the college educated American women who have that level of health in 2002.

Following the characteristics approach we have:

$$k_{i,t} = C_{i,t}(a) = 55.94$$

where k is the health score at the given calendar age $a = PHAT_{female}$ for the female population i in the year $t = 2002$.

To find out at what age the female population i in the year $\tilde{t} = 2002$ has the same level health, $k_{i,t}$, we use:

$$\propto_{i,\tilde{t}} = C_{i,\tilde{t}}^{-1}\left(C_{i,t}(a)\right) = C_{i,\tilde{t}}^{-1}(55.94) \approx 77.91$$

Therefore, an average college educated American women at PHAT in 2002, in terms of health, would be 77.91 years old if compared to average women in both ELSA and HRS samples in 2002.

Following the procedure described above, we calculate prospective health ages of individuals with different education levels separately for each survey and gender. The procedure is similar as the one used to calculate the aggregate health-age-year nexus: the representative ages at which individuals of different educational categories reach the respective PHATs are calculated by fitting second-degree polynomial curves of the health score on age, age squared and a dummy variable indicating whether the person has a college education. We repeat the procedure for 100 random draws of single observations per individual, independently by gender, year and study (see Appendix

[5] Formally, a characteristic schedule is defined as $k = C_r(a)$, where k is the level of the characteristic observed at age a in population r. Let k be the standard of comparison. The characteristics function $C(.)$ can be inverted (under the assumption of continuity and monotonicity) to obtain characteristic based ages, denominated in general as "alpha ages" for any population different than r. For example, to find the alpha age of population s when compared to the standard level k of population r, we calculate $\propto = C_s^{-1}\left(C_r(a)\right)$

B for the estimated coefficients and their corresponding statistical significance). We can see the calculated PHAs numerically in Table 5 and graphically in Figures 5 and 6.

Table 5: Prospective health ages by gender at different levels of education, England and USA, 2002 to 2012

(a) Females

	Prospective health ages for females*			
Year	England (ELSA)		USA (HRS)	
	No College	With College	No College	With College
2002	70.33	85.93	64.73	77.91
2004	72.60	81.26	60.72	77.40
2006	73.66	83.01	62.46	76.38
2008	73.87	80.42	64.37	74.54
2010	74.08	80.33	63.04	75.61
2012	76.34	80.90	65.13	79.20
mean :	73.48	81.97	63.41	76.84

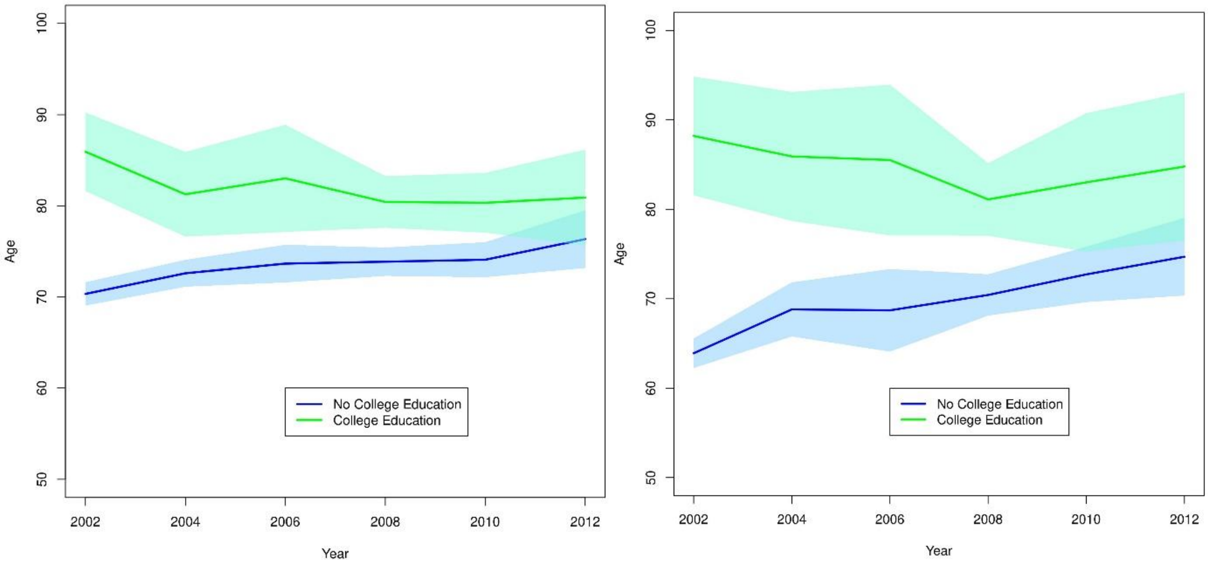
(b) Males

	Prospective health ages for males*			
Year	England (ELSA)		USA (HRS)	
	No College	With College	No College	With College
2002	63.90	88.20	57.18	73.96
2004	68.81	85.91	57.46	75.71
2006	68.70	85.51	60.59	74.40
2008	70.42	81.10	60.68	74.94
2010	72.72	83.01	58.27	74.49
2012	74.70	84.78	61.84	73.93
mean :	69.88	84.75	59.34	74.57

Note : * Prospective health ages are calculated separately for each gender, given that estimated average level of health at the prospective health age threshold is 55.94 for females, and 60.07 for males.

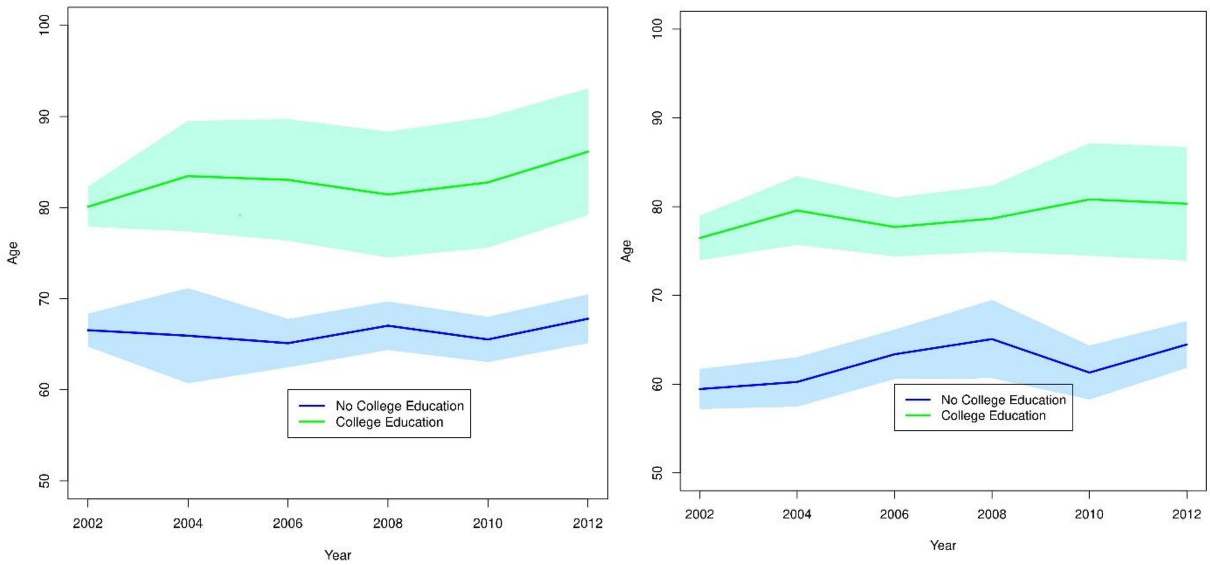
We find significant differences in the health-age patterns by education in both samples. First, it is noticeable that college-educated individuals are, on average, much healthier than their counterparts with no college degree. The difference in prospective health age between the college and non-college groups is around 8.5 years for females and 15 years for males in the ELSA sample. The corresponding figures in the HRS sample are 13.4 and 15.2 years. These results also imply that health inequality, especially for women, is much bigger in the USA than England.

Figure 5: Comparison of trajectories of health by education based on gender-specific prospective health age thresholds (PHAT), England (ELSA), from 2002 to 2012



(a) Females (b) Males

Figure 6: Comparison of trajectories of health by education based on gender-specific prospective health age thresholds (PHAT), USA (HRS), from 2002 to 2012



(a) Females (b) Males

Across countries, the results show that Americans, in average, have worse health than their counterparts in England. For example, among those with no college degree, British, on average, are much healthier than their American counterparts are. Indeed, they have the same level of health later (i.e., 10 years for females and 10.5 years for males) than their peers in the USA. Looking at prospective health ages of those who hold at least a college degree, again we observe the inequality in health, but to a lesser extent. Moreover, in the observed period, the improvements in health in the USA fall behind those seen in England, which widens the gap in health between these two countries. In particular, there seems to be a significant decrease in the educational gap in the ELSA sample for both females and males, while, on the contrary, the differences remain more or less constant in the HRS. Overall, these results are consistent with results from the literature that show that Americans tend to have worse health than the English and that the educational/income gradient is wider in the case of the US [11, 14, 15].

4. Concluding remarks

The results presented in this paper show that chronological age fails to reflect some of the important characteristics related to the ageing process. We know that the average lifespan of individuals is increasing over time. According to this, the conventional aging approach, which defines the beginning of old age based on a fixed chronological age, implies that individuals of consecutive cohorts would spend an increasing number of years at old ages. On the other hand, the prospective measurement strategy proposes the opposite view: by defining old age according to remaining life expectancy, individuals in subsequent cohorts spend the same amount of years at old age, while their number of years before old age increase. Here we show that, if the ageing process is closely related to the health of individuals, the prospective age measure is a better measure of ageing than the standard measure, as, at a fixed chronological age, health is improving over time, while, on the other hand, life expectancy and health tend to move in parallel.

We use this feature of POAT to define the health at the onset of the old age, which we call “prospective old age threshold”. We show that this alternative age measure based on health can be used in a variety of contexts and facilitate the comparisons of healthy ageing trajectories across different populations. Indeed, using this new measure, we compare the health based aging trajectories by education for the birth cohorts observed in ELSA and HRS and show that there is an important inequality in health and, therefore, aging across different education categories both in the US and England, albeit smaller in the latter. We also show that the gap is always larger for males.

There are several implications of our results. First, they give strong support to the use of the POAT as defined by Sanderson and Scherbov [6, 9] as a better representation of the ageing process. It also supports the validity of the composite health metric designed by Caballero et al. [12] and de la Fuente et al. [13] as a proper summary measure of healthy ageing. Finally, and also on the policy side, it provides additional support to the argument that increasing the education level of the population could imply significant gains in terms of healthy ageing.

References

1. Christensen K., Doblhammer G., Rau R. & Vaupel J. W. Ageing populations: the challenges ahead. *The Lancet* 374, 1196–1208, (2009).

2. McLaughlin S. J., Jette A. M. & Connell C. M. An examination of healthy aging across a conceptual continuum: Prevalence estimates, demographic patterns, and validity. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences* 67, 783–789, (2012).

3. Max Planck Institute for Demographic Research, University of California Berkeley. *Human mortality database*.

4. Lutz W., Butz W. P & KC S. World population & human capital in the twenty-first century (2014).

5. Department of Economic and Social Affairs. *World population prospects* (2017).

6. Sanderson W. C. & Scherbov S. Rethinking age and aging. *Population Bulletin* 63, 1–16 (2008).

7. Sanderson W. C. & Scherbov, S. Remeasuring aging. *Science* 329, 1287–1288, (2010).

8. Sanderson W. C. & Scherbov S. The characteristics approach to the measurement of population aging. *Population and Development Review* 39 (4): 673-685, (2013).

9. Sanderson, W. C. & Scherbov, S. Average remaining lifetimes can increase as human populations age. *Nature* 435, 811–3 (2005).

10. WHO. World Health Statistics 2017: Monitoring health for the SDGs. World Health Organization (2017)

11. Crimmins, E.M., Garcia, K & Kim, J.K. Are International Differences in Health Similar to International Differences in Life Expectancy? *International Differences in Mortality at Older Ages: Dimensions and Sources* (2010).

12. Caballero F. F. et al. Advanced analytical methodologies for measuring healthy ageing and its determinants, using factor analysis and machine learning techniques: the ATHLOS project. *Scientific Reports* 7, 43955, (2017).

13. de la Fuente, J. et al. Determinants of health trajectories in England and the United States: An approach to identify different patterns of healthy aging. *The Journals Gerontol. Ser. A* 73, 1512–1518, (2018).

14. Avendano, M., Glymour, M., Banks, J., and Mackenbach, J.P. Health disadvantage in U.S. adults aged 50-74 years: A comparison of the health of rich and poor Americans with that of Europeans. *American Journal of Public Health*, 99, 540-548 (2009).

15. Banks, J., Marmot, M., Oldfield, Z., and Smith, J.P. Disease and disadvantage in the United States and in England. *Journal of the American Medical Association*, 295, 2037-2045 (2006).

Appendix A: Illustration of the calculation of prospective old age thresholds (POAT)

Table A.1 shows hypothetical life expectancies for group i between ages of 65 and 67 over the period t to t+5. To find the prospective old age thresholds (POAT), we look for the ages corresponding to a remaining life expectancy of 15 years in each column.

Table A.1: Hypothetical life expectancies (e_i) between ages 67 and 69 for the years t through t+5

	Year					
Age	t	t+1	t+1	t+3	t+4	t+5
67.0	15.00	15.20	15.40	15.60	15.80	16.00
67.1	14.95	15.15	15.35	15.55	15.75	15.95
67.2	14.90	15.10	15.30	15.50	15.70	15.90
67.3	14.85	15.05	15.25	15.45	15.65	15.85
67.4	14.80	15.00	15.20	15.40	15.60	15.80
67.5	14.75	14.95	15.15	15.35	15.55	15.75
67.6	14.70	14.90	15.10	15.30	15.50	15.70
67.7	14.65	14.85	15.05	15.25	15.45	15.65
67.8	14.60	14.80	15.00	15.20	15.40	15.60
67.9	14.55	14.75	14.95	15.15	15.35	15.55
68.0	14.50	14.70	14.90	15.10	15.30	15.50
68.1	14.45	14.65	14.85	15.05	15.25	15.45
68.2	14.40	14.60	14.80	15.00	15.20	15.40
68.3	14.35	14.55	14.75	14.95	15.15	15.35
68.4	14.30	14.50	14.70	14.90	15.10	15.30
68.5	14.25	14.45	14.65	14.85	15.05	15.25
68.6	14.20	14.40	14.60	14.80	15.00	15.20
68.7	14.15	14.35	14.55	14.75	14.95	15.15
68.8	14.10	14.30	14.50	14.70	14.90	15.10
68.9	14.05	14.25	14.45	14.65	14.85	15.05
69.0	14.00	14.20	14.40	14.60	14.80	15.00

The table of POATs would then be:

Year	POAT
t	67.0
t+1	67.4
t+1	67.8
t+3	68.2
t+4	68.6
t+5	69.0